EFAB-Environmental Fabrication: Towards a Confluence of Craft & Computing in Prefabricated Component Design

Santiago R. Perez
University of Houston

Fig. 1. Pavilion Frame and Modular Skin Mold

Abstract

What is the relation between an Ethic/Logic of Craft and Making, and Advanced Digital Fabrication?

How can Prefabricated Assemblies serve as experimental platforms for development of new "Material Ecologies"?

Environmental suggests external relations, material resistance and programmatic, spatial, and site-specific criteria affecting both the strategies and outcome of MAKING. *(Pre)**Fabrication*** strategies and goals are inherently procedural, based on specific tools and material properties and following internal logic and constraints.

This essay will research the primary relations between (hand) Craft & Advanced Digital Fabrication methods, towards development of new material/component systems or *Environmental Fabrication.* The shift from formal speculation, typical of early experiments with digital fabrication, to the potential afforded by combining generative strategies with environmentally strategic research and production, forms the main topic of research, as related to prefabricated component and skin systems. 20th century material/component systems exploration, by architects such as Prouvé and Fisac, forms the backdrop for this research, in comparison with emerging material practices. The goal of this research is to develop an understanding of "nature" as a *Performative Component Framework* for Advanced Prefabricated Assemblies.

Introduction

Fig. 2. Laser-Cut Plywood Skin

Computational Craft, or the act of combining jigs, formwork and other methods of hand making, with advanced computationally intensive fabrication methods, create hybrid methodologies for prefabrication (see Fig. 1).

Malcolm McCullough, in his book *Abstracting Craft*, has suggested that hands are underrated when it comes to acquiring knowledge of the world and, ultimately, of complex systems.[1] Following in the tradition of Polanyi, in *Personal Knowledge,* McCullough suggests that tacit knowledge is acquired not only by the hands, but also by the entire body, in its interaction with objects in space.

"Hands also Discover. They have a life of their own that leads them into explorations. For example, a sculptor's feel for a material will suggest actions to try, and places to cut. Learning through the hands shapes creativity itself." (McCullough, 1996)

The tactile or haptic quality afforded by direct interaction with material craft must be balanced with an awareness of the increasing distance between the act of design and making. The process of developing new prefabricated component systems combining easily manipulated materials such as bent plywood creates an accessible point of entry for students interested in developing large-scale work. The confluence of "low-tech" methods with emerging material exploration, computational (generative) methods, and biomimetic (performance-based) explorations, promises to open up new territories for prefabrication.

This culture of material experimentation has a deep legacy in architecture, from the experiments of Piano, to the work of Shigeru Ban. Emerging practices in prefabrication have only scratched the surface of the confluence of technology and craft: what the author terms **EFAB.**

Component Design

Fig. 3. Laminated Tensegrity System Joint

Michael Stacey, in his book *Component Design,* addresses the need for understanding how to select and combine available and emerging materials towards prefabricated component systems. Stacey views component design and prefabrication as both a selection process, using open, industrial systems, and a research and development process, producing customized closed-system components for specific applications. He understands construction from the perspective of industrial manufacturing, and advocates that architects learn manufacturing technologies in the manner of Industrial Design. The Joint, in this context, becomes a point of reference, not only for the geometric grid but also as a marker of Technology Transfer. The joint absorbs or adapts dissimilar material logics or systems into a continuous performative, synergistic whole. Stacey emphasizes the need for a comprehensive understanding of (advanced) material systems and detailing, from a rational, technical viewpoint, but also in the service of what Peter Zumthor terms "the art of making a meaningful whole out of many parts."[2]

If we move from components as individual parts to a notion of assemblies, or collections of parts with related functional performance, we arrive at what Kieran and Timberlake term Elements. Framing the concept of an integrated technical assembly as a group of components or elements, allows for a hierarchical development of part to whole, and begins to shift the concept of prefabricated component assemblies from Construction to ***Assembly,*** as implemented in Kieran and Timberlake's Loblolly house.[3]

In the framework of the EFAB studios, several variations of hierarchical component systems have emerged. The first is the relation between NODE and TRUSS or CORD, as developed in a tensegrity tower utilizing shaped bent plywood node connections and cord elements. The integration of contoured or shaped profiles for both the node and cord members allows for the possibility of responsive or adaptive variations in the standard profile of each element in response to differential loading conditions. Multiple variations of NODE and CORD elements were prototyped at a small scale prior to the production of a full-scale, 30 ft. high prototype.

The second component system was developed as a test-platform for various performative assemblies, using the Pavilion as an archetype. Four interrelated system assemblies were produced, in addition to a freestanding parametric wall system.

FRAME, FLOOR, SKIN, and PANEL systems were produced concurrently, with each team adapting to the contingencies of emerging assemblies, in real time. This resulted in a hybrid condition, with a glue-laminated plywood frame as the primary structure. Secondary systems were produced utilizing plastic and metal components, which were prefabricated utilizing 3D-printing, casting and thermoforming technologies.

Reflective Fabrication

The development of a ***"Reflective Fabrication Practice"*** is one of the primary goals of the EFAB studio, to borrow Donald Schön's terminology.[4] From a pedagogical perspective, the development of prefabricated component assemblies serves as a vehicle for encountering the limitations of working at full scale with the actual materiality of the building process. The encounter with materiality, under the controlled conditions of the shop or fabrication center, affords students the capacity to develop a "considered" or reflective attitude towards the prefabricated technical object. Shone stresses the need to rethink design and making, from an emphasis on Positivist Technical Rationality, towards a Humanist ideal of reflection-in-action (Shone 1983). In a Technical Practice, the emphasis is on applied knowledge, and skills, based on a standardized body of specialized knowledge. Theoretical research, by comparison, stresses the development of new forms of basic knowledge pertaining to a specific field of inquiry. Within the context of teaching advanced fabrication studios, the combination of detached, disciplined knowledge with hands-on skill with material, forms the basis for ***Theoretical Practice.*** The architect David Chipperfield, to describe his interest in combining knowledge and craftsmanship towards architecture, has used this term, perhaps in a different context, in his early work.

Prefabricated component design provides a basis for engaging both material practice and theoretical knowledge. It requires an intuitive feel for the limits of material, skill in craftsmanship, and theoretical knowledge of the interrelationship among components, the relation of part to whole, and the evolution of new composite materials.

Beyond the engagement with material, per se, the development of Material Systems or Logic shifts the focus from the Technical Object towards the notion of an Ecology of interrelated parts or systems. Material Ecologies, to use Neri Oxman's phrase, engage materiality and making as a Theoretical Practice, requiring the development of new modes of engagement and production of the Technical Object as an embedded material system, with performative responsive and adaptive logic of assembly and production.

Schön, in developing a thesis towards Reflection in Action, stresses the need to overcome the limitation of Instrumental Rationality. His notion of an "Intelligent Practice" or "Knowing in Action" may be applied to the development of a pedagogical framework for studio-based development of prefabricated assemblies:

"Once we put aside the model of Technical Rationality, which leads us to think of intelligent practice as an application of knowledge to instrumental decisions, there is nothing strange about the idea that a kind of knowing in inherent in intelligent action."[5]

This manner of thinking through problems of materiality has a long history, and has also informed recent emerging modes of fabrication, such as the "soft" formwork utilized in Mark West's flexible fabric concrete formwork innovations in the Canadian Centre for Architectural Structures and Technology, at the University of Manitoba.

A central aspect of Reflection in Action is the concept of ***Improvisation***. In the context of the emerging work of the EFAB studio, improvisation is central to the idea of **making** as an intellectual activity, capable of forming new modes of engagement with material systems through the tacit knowledge gained by direct physical manipulation of material.

Within the context of prefabricated assemblies, the Improvised Component is both *Designed and Evolved.* Design suggests access to a specialized body of received knowledge: instrumental rationality. However, design is also an intuitive, improvisational activity, dependent on real-time engagement with physical processes. The development of component systems requires both intuitive and empirical knowledge, both qualitative and quantifiable characteristics of material. Within this framework, a closer look at the term "Technical Object" is needed.

Prouvé: Poetics of the Technical Object

The recent reemergence of interest in Prouvé's work, methods and thinking, culminated in an exhibition and publication by the Vitra Design Museum.[6] Prouvé was both architect and "designer-constructeur." He rebelled against the notion of the "Grand Vision," instead concentrating on the development of practical solutions to building through the use of prefabricated component assemblies. As Bruno Reichlin has observed, Prouvé was interested in the division of labor but also in the integration of multiple material systems and practices under the umbrella of industrial production and management. In his essay "Technical Thought, Techniques of Thinking," Reichlin attempts to map the relation between Technical Rationality and Humanist Ideals within the complex development of Prouvé's prefabricated systems or "factoried" constructions. The notion of a fully integrated, "concrete" (manifested) functional Technical Object is posited as a ***Synergistic*** relation of part to whole:

"the concrete technological object is one that is no longer struggling against itself, one in which no secondary effect is harmful to the functioning of the whole, or extraneous to that functioning. Thus, and for this reason, in a concretized technological object, a function can be fulfilled by several structures associated in synergy whereas in a primitive, abstract technological object each structure is required to fulfill a specific function, generally a single one."[7]

The Technical Object can thus be seen as both Machinic, or Industrial, in the sense of embodying functional clarity and economy, and also as an adaptive, evolutionary, performative aspect of synergy more closely resembling biological organisms or ecologies of form. The recently rebuilt Aluminum Centenary Pavilion illustrates the concept of synergy embodied by technical systems, utilizing complex component forms in the service of producing a lightweight, prefabricated pavilion.

Among Prouvé's diverse constructions, the shed roof components serve to illustrate the economy of repetition and customization in a mass-produced, lightweight tectonic system. These prefabricated shells are composed of complex sections incorporating lighting and waterproofing, in addition to their self-supporting structural characteristics. A comparison can be made between the component-assemblages of Prouvé's sheds, and the concrete shell structures of the Spanish architect Miguel Fisac.

Fisac's Bones

The Water Studies Center in Madrid, by Miguel Fisac, incorporates long-span post-stressed concrete component shells. These prefabricated one-meter long hollow shells are aggregated along the length of the span, creating a continuous beam structure from individual component parts. The elegance and economy of forms is derived from Fisac's fascination and analysis of natural *bones.* His interest in understanding how nature optimizes both the solid material and the void-forms in bones, led him to develop an industrial system composed of prefabricated Technical Objects embodying the principle of synergy advocated by Simondon and Reichlin in reference to Prouvé. However, whereas Prouvé's shed roof structures depend on a concrete beam for support, Fisac incorporated the beam's structural performance within the shell-form itself, using post-tensioned steel at the three support vertices of the shell.

We can see the incorporation of both an industrial rationality of prefabricated components, and an adaptive, bioperformative derivation of natural form in the work of Fisac.

Computational Crafting

Both Prouvé and Fisac serve as examples of precursors to "Technical Thinking" within the context of current computational design and fabrication culture. The emphasis on empirical methods and material investigation, combined with the optimization of form and structure through analysis of nature as a performative (rather than aesthetic) reference, allowed both Prouvé and Fisac to develop complex, functional prefabricated component systems.

Today we have the opportunity to consider component systems from the perspective of ***Parametric*** control of both the methods of production (CNC) and the abstract modeling of form as Technical Object or system. This unprecedented computational potential has had little impact on the modular prefab industry, affecting only the efficiency and speed of production, with little or no impact on the development of new forms and material systems. The exception to this is the experimental work of material practices immersed in digital culture, such as the work of SHoP architects, or the prefabricated and off-the shelf innovative systems utilized by William Massie. These are isolated instances of innovation in an otherwise stagnant culture of prefabrication, when compared with the achievements of Prouvé and Fisac.

Parametric Formwork

Fig. 4. Parametric Concrete Units

A possibility for innovation emerges when the functional object is reconsidered as a ***Technical System,*** rather than a discrete object. One result of the recent EFAB studios has been the development of modular, reusable molds, capable of reconfiguration of form, adapting to changes in geometry. These ***Parametric Formworks*** support an efficient and rapid fabrication process while allowing changes in curvature or profile, forming a link between the digital, computational model, and the physical discovery and manipulation of material form (See Fig. 4). Parametric mold systems are one-to-one mapping of data points or clouds, from the digital model to the physical armature or scaffold, used to cast or otherwise shape a material system. While still very crude in its current incarnation, the parametric systems being developed in the EFAB studios suggest that a new "object intelligence" may be produced. These form-finding experiments inherit the legacy of Heinz Isler and Frei Otto, embedding Technical Thinking within a digital/material culture of prefabricated component design.

Notes

[1] McCullough, M. (1996) *Abstracting Craft: The Practiced Digital Hand.* Cambridge, Massachusetts: MIT Press.

[2] Zumthor is quoted by Stacey in *Component Design.* The introduction to Component Design was published in the 2004 ACADIA Fabrication Conference Proceedings.

[3] Kieran, S. and J. Timberlake. (2008) *Loblolly House: Elements of a New Architecture.* New York: Princeton Architectural Press.

[4] Schon, D. (1983) *The Reflective Practitioner.* New York: Basic Books.

[5] Schon, p. 50.

[6] Vegesack, A. ed. (2005) *Jean Prouvé: The Poetics of the Technical Object.* Weil am Rhein: Vitra.

[7] Reichlin is quoting Gilbert Simondon's "Modes of Existence of Technological Objects." See Bruno Reichlin, *Technical Thought, Techniques of Thinking,* in Vegesack, p. 34.